



ULTRASONIC COMPUTER STORAGE

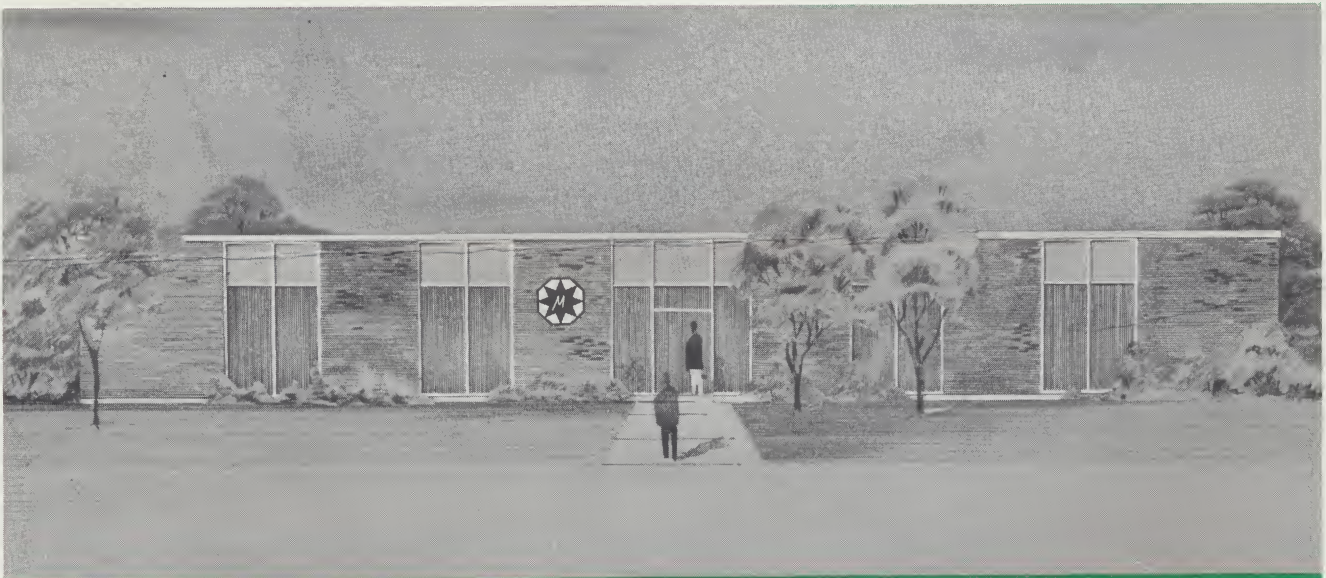
MICROSONICS



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ULTRASONIC COMPUTER STORAGE



Microsonics' new facilities in Weymouth (Boston), Massachusetts, are ideally staffed with both personnel and equipment to handle design and development of Ultrasonic Delay Lines and Crystal Filters. Our quality control procedures are approved for both military and space applications.

ULTRASONIC STORAGE SYSTEMS

Ultrasonic delay lines have been used for storage of many types of information. They have found a special field of analog storage in many applications of radar data processing. These high frequency delay lines use fused quartz or special glasses for a medium of delay together with a variety of transducers depending on the requirement. These delay lines have many unique characteristics which make them ideal for storage of information.

1. Wide bandwidth — Bandwidths from 5 to 20 MC can be readily achieved.
2. Low Spurious — All undesired signals are 35 to 50 db below the desired output signal.
3. Linearity — The delay lines have unlimited linearity. There is no saturation effect and the line may be driven with voltage levels from milli-volts to hundreds of volts with no change in performance.

These three characteristics have resulted in wide usage of delay lines for radar data storage and processing. The reliability, low cost, and small size and weight of delay line storage has precluded the use of digital techniques in many cases.

Recently there has been an increasing interest in high frequency ultrasonic delay lines for use in computer storage systems. These lines can operate at frequencies up to 30 MC. Thus, operation at high bit rates can result in a much smaller access time for a given bit storage capacity. Complete storage systems have been manufactured using 14 separate channels of 20,000 bits in each channel.

Delay Time

One of the major considerations of the delay line storage system is that the delay time of delay lines must be maintained in absolute time in order to provide proper retiming against the master clock which is also operating in real time. This means that the delay must be constant within $\frac{1}{4}$ bit and measurement techniques have been developed to accurately measure absolute time delay to 1 nano-second. The simple problem is to keep the delay constant over a change in temperature. There are two generally accepted solutions. One is to use a special glass which has zero temperature coefficient (ZTC) of delay. This glass has a modified structure in which the positive linear expansion of the glass

is balanced against the negative change in velocity. This gives an approximately zero temperature coefficient of delay over a limited range around 25 degrees Centigrade. This type of delay line has provided a very useful material for short delay lines up to 200 usec. Unfortunately, the glass has a high loss which makes for limited use above this length.

To provide longer delays, fused quartz must be used, since it has very low losses even at high frequencies up to 60 MC. The temperature coefficient of delay for fused quartz is 75 ppm per degree Centigrade. To provide stable time delay a temperature control system is required. Figure 1 shows the relationship between total bit capacity and degree of temperature control required. A temperature control of 1°C will be sufficient to handle 3,000 bit storage and 01°C will handle 30,000 bits. This accuracy of control has become routine design for Microsonics where temperature control to $.005^{\circ}\text{C}$ has been obtained. The same temperature control can be used for many delay lines by enclosure in the same physical structure. Microsonics has controlled up to 40 delay lines in one oven with each line having a 4200 bit storage.

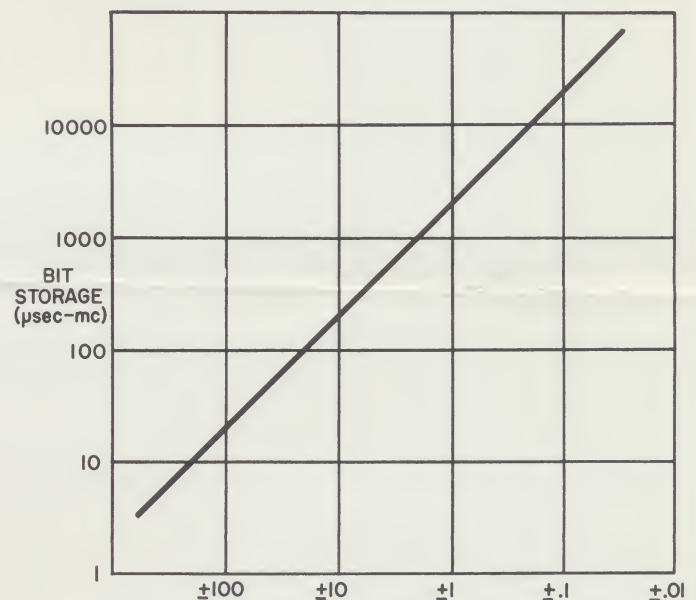


Figure 1 — Temperature Control

A third solution to the temperature control and time delay problem is to use a variable clock frequency so that the change in time delay will result in an error signal to correct the crystal

oscillator and maintain the same number of bits in the delay line. Microsonics has developed such a system for special applications where heater power is limited but high speed, reliable, delay line storage is necessary.

Frequency Response

The delay line response is mainly determined by the frequency response of the transducers which are used on the delay lines. The general shape of the transducer response is shown in Figure 2. It should be noted that the transducers have maximum response at the resonant frequency of the transducer with 3 db bandwidths up to 50% of the center frequency. The response goes to zero at zero frequency and at twice the transducer frequency. This

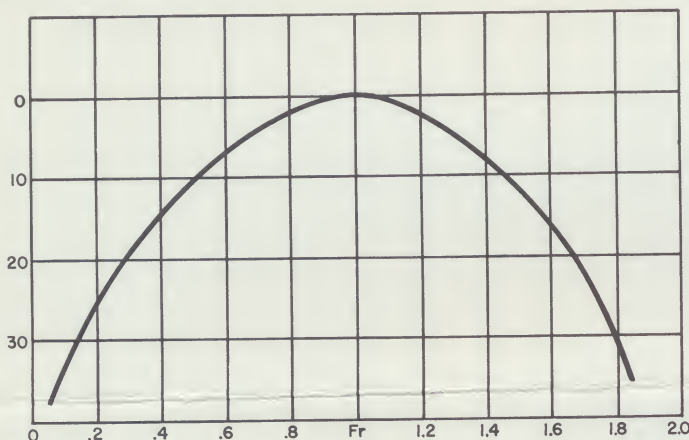


Figure 2 - Normalized Frequency

overall bandpass can be shifted by the loss in the material which has a linear increase in attenuation with frequency. For ZTC glass lines the glass loss can be so high as to ultimately limit the high frequency end of the bandpass. The ultrasonic delay line by its fundamental properties is a bandpass device of broad bandwidth centered at the frequency region from 5 to 60 MC. This frequency being determined by the resonant frequencies of the transducers.

Pulse Response

From the frequency response it can be seen that an ultrasonic delay line will not give true response to a pulse signal. Any delay line using an electro mechanical transducer will not respond to a continuous dc level. The transducer will only respond to the change in level represented by the rise and fall time of the pulse. In fact, the actual output response can be analyzed on the basis of

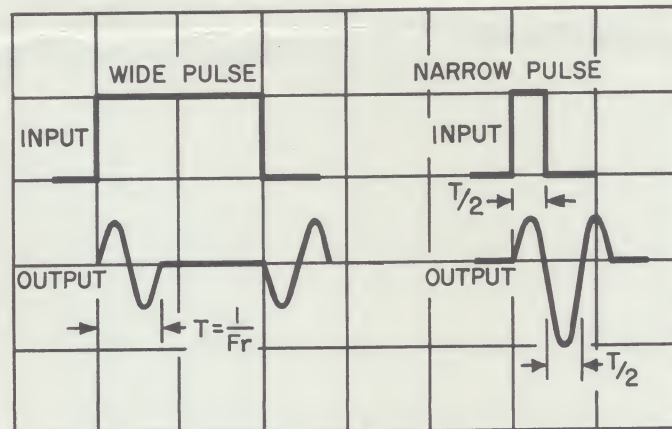


Figure 3 - Ideal Pulse Waveforms

the impulse function of the frequency response of the delay line. If the delay line has very wide bandwidth then the idealized waveforms of Figure 3 will be realized. The period of the resultant output waveform is $1/FR$ where FR is the center frequency of the bandpass of delay line. For a wide pulse there are two separate doublets corresponding to the rise and fall times of the input pulse. If the input pulse has a pulse width equivalent to $T/2$ then the two doublets will merge into a triplet in which the adjacent negative waveforms add together to give twice the separate amplitudes. As shown in Figure 3 the output pulse is negative for a positive input pulse. The output pulse can be either positive or negative depending on the phasing of the output leads.

For a given pulse width corresponding to a specific bit rate the frequency response of the delay line must be designed to give the proper triplet response. The pulse width may be varied 10 to 20% without seriously affecting the optimum triplet response.

The actual response of a delay line with a limited bandwidth is shown in Figure 4. It can be seen that the original doublet has become a decaying sine wave function. The narrower the band-

width; the more ringing that will occur. In addition, for long delay lines, there will be some dispersion which will result in frequency being spread out in time. For the optimum input pulse of $T/2$ the output pulse will be non-symmetrical followed by an extra half cycle. This lobe is the most serious spurious signal since it will fall in the time segment for the next pulse. The ratio of the main lobe to the secondary lobe generally defines the signal to noise ratio of the delay line.

Microsonics has developed design techniques for matching the acoustic impedances of the transducers and the delay medium, for wide frequency response. This will result in digital lines with excellent pulse response and low spurious signals. Delay lines are available in the following types:

1. ZTC Glass — Delays up to 200 usec
 - a. Ceramic transducers — freq. rates up to 5 MC
 - b. Quartz transducers — freq. rates up to 25 MC
2. Fused Quartz — Delays up to 5000 usec
 - a. Ceramic transducers — freq. rates up to 5 MC
 - b. Quartz transducers — freq. rates up to 25 MC

Since the interface problem between delay line and circuitry can be very important to the overall

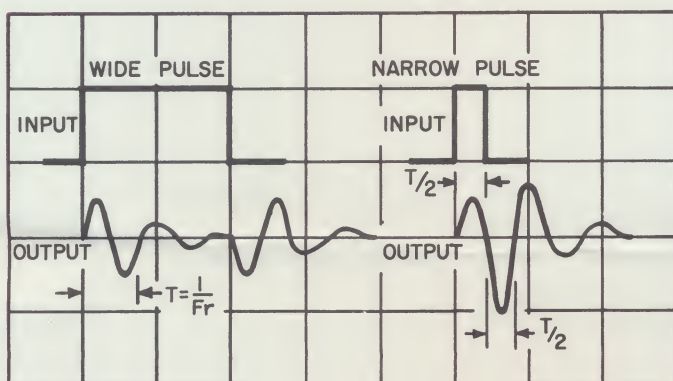


Figure 4 — Actual Pulse Waveforms

performance Microsonics has proven capability in the design of drivers and post delay amplifiers to provide a unity gain system as a single component of memory storage. Every application requires a special combination of transducer, delay line material, physical package, and circuit layout. Microsonics would be available with engineering assistance as required.

New Applications

The pulse use of ultrasonic delay line is a simple method of storage which does not use the capabilities of the device to its fullest advantage. The delay line is a bandpass device with wide bandwidth centered at some specific frequency. Best utilization of the bandwidth can be obtained by making the frequency spectrum of the pulse match the frequency spectrum of the delay line. Then, maximum energy transfer is realized and the attenuation of the delay line will be reduced. This is accomplished by modulating the pulse on a car-

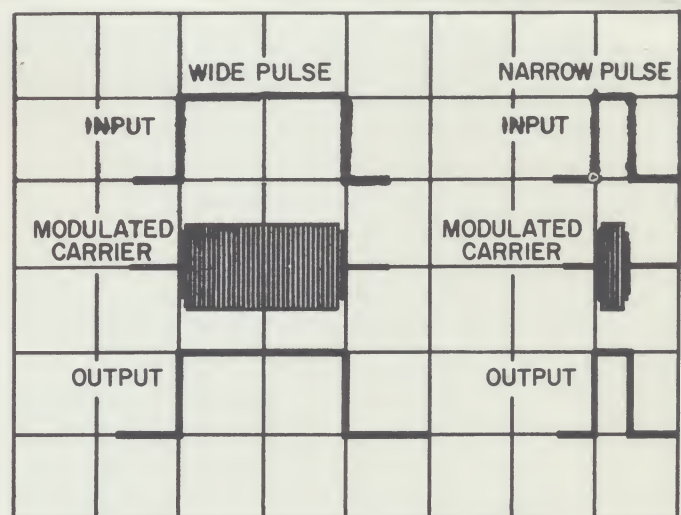


Figure 5 — Pulse Carrier Waveforms

rier to shift the spectrum up to the carrier frequency. The advantages to this approach are:

1. Lower attenuation — better energy transfer.
2. Less Spurious — There are no additional spurious lobes as shown in Fig 5.
3. No Dispersion — Dispersion becomes much reduced above 15 MC so that it is of no consequence with carriers 30 MC or above.

The use of pulse carrier waveforms removes many constraints which are present on pulse delay lines. The delay line need no longer be designed around a specific pulse width or around a specific pulse code. The delay line will handle a very wide change in pulse widths and the pulse code can be RZ or NRZ without any change in delay line design. Therefore, this carrier pulse method makes for a

completely versatile storage system. This approach has been made successful by the development of simple transistor circuits for the associated drivers and amplifiers. For example, even, at 20 MC bit rates, the driver to convert the pulse to a 3 volt pulse carrier, consists of only one transistor stage. Microsonics has approached the ultrasonic storage system from the unity gain, integrated design as the best method of attaining maximum performance.

Once the concept of storage systems is applied, the possibilities of design are greatly increased. The following is a discussion of some of these designs.

1. High Bit Rates — Information rates up to 25 MC can be obtained with no specific limitation on delay line length. A specific example of this is shown in Figure 6 which are actual waveforms of

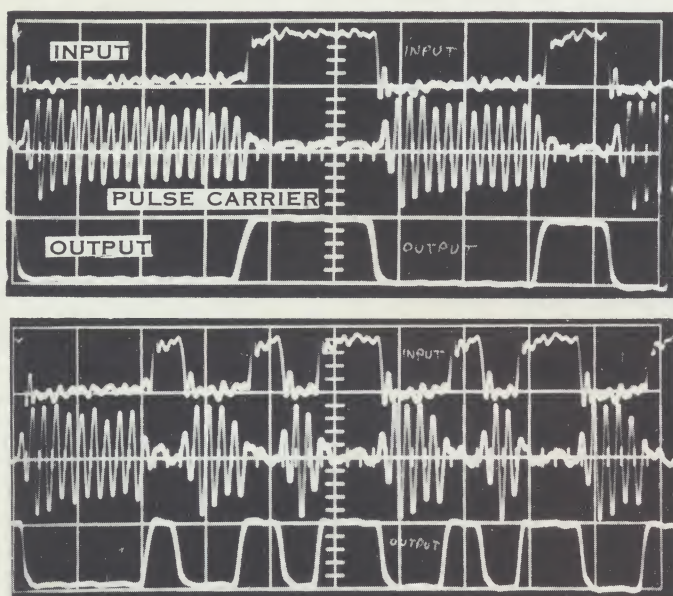


Figure 6 — Ultrasonic Storage Waveforms 20 Mc NRZ

a 20 MC NRZ system using a 1000 usec delay line for a total storage of 20,000 bits per delay line. The upper trace shows the input pulse with negative level representing a logical "one." The irregularities of the waveform are due to cable mismatch and 20 MC clock leakage. The middle waveform shows the pulse carrier which drives the delay line and the bottom trace shows the output signal from the post delay amplifier. It should be noted that this signal has not been reclocked but, demonstrates the degree of pulse fidelity which can be achieved. There are no spurious lobes, no pulse ringing, no phase distortion, and no problem with various width pulses. These same waveforms would apply regardless of delay line length, and information rate since the carrier is simply gated by the input waveform.

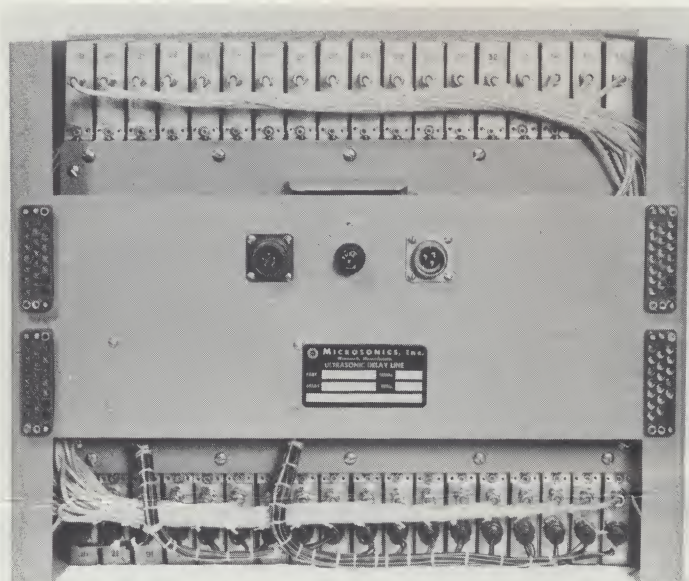


Figure 7 — 36-Channel Storage System (Back View)

2. Large Storage Capacity — The pulse carrier method as shown removes the limitation of long delay lines with high storage rates. Thus, 20,000 bits can be stored in 1000 usec lines at 20 MC, 15,000 bits can be stored in 3000 usec lines at 5 MC. Many parallel channels can be added stacking more modules in the same package. Figure 7 shows a complete storage system which was designed to operate at various rates from 2 to 5 MC without adjustment. At the higher rate one channel will store 4200 bits making a total capacity of 151,200 for the entire 36 channels. This type of storage is similar to a multitrack storage drum except that there are no moving parts, and the information moves through a mechanical or ultrasonic motion from input to output. This ultrasonic storage is completely free from shock or Vibrational effects as shown by its reliability in many military systems.

3. Multiple Channels — The frequency bandwidth of the delay line can be up to 20 MC wide at high transducer frequencies. This bandwidth cannot be fully used with a single channel of low frequency bit rates. By the use of multiple frequencies through the same delay line it is possible to have many smaller bandwidth channels within the same delay line. This makes use of the dual property of wide bandwidth and complete linearity. Many pulse carriers can be present simultaneously in the delay line with absolutely no intermodulation of the signals. The pulse carrier frequency becomes another independent variable which may be used to provide more storage per delay line. This technique can provide up to 5 parallel channels in the same delay line with the added advantage of absolute time match between channels.

4. **Versatile storage** — As previously discussed the ultrasonic storage system will handle a wide variety of signals without change or adjustment. The system is not limited to a binary code since the delay line will recognize many different levels. The same delay line will therefore, handle decimal information or any specific intermediate coding. It is also possible to combine level coding system together with multiple frequency channels to give even further storage capacity.

Microsonics has developed a proprietary technique so that with multiple levels on a single frequency, three separate information channels can be handled simultaneously in a single delay line. This is accomplished without any increase in bandwidth over a single information channel. By this method a 3000 usec delay line operating at a 5 MC rate was shown to be capable of storing 45,000 bits and 12 channels could provide over 0.5 million bit memory.

APPLICATIONS

The proven reliability of ultrasonic storage systems at high information rates gives long term service in difficult environments of shock, vibration and temperature. Either pulse delay lines or pulse carrier delay lines can be used depending on the particular requirement and the necessity for maximum storage. Microsonics has complete facilities to handle any portion of a storage requirement.

1. Single delay lines
2. Multiple delay lines
3. Large temperature controlled delay line packages
4. Overall storage systems

Ultrasonic storage systems should be considered for any of the following applications:

Shift Registers
Buffer Storage
Scratch-pad Memories
Process Control Storage
Time Compression

In addition the larger systems can be used for main storage in small to medium size special purpose computers.

The concept of limited use of ultrasonic storage systems must be revised with the new techniques which are now available. Microsonics will provide the engineering assistance to evaluate the optimum storage for any requirement.



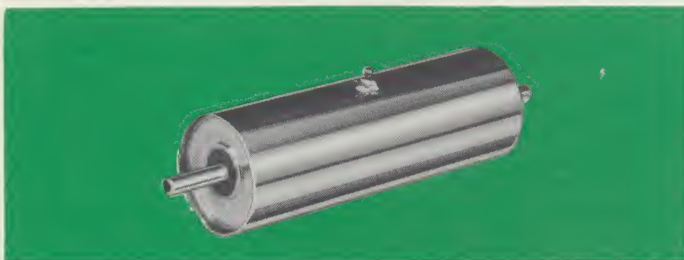
Other Microsonics Products



Tapped Ultrasonic Delay Lines

Multiple inputs and outputs available on Microsonics ultrasonic delay lines add new versatility in applications to pulse code modulation, pulse compression, staggered repetition rates, timing systems and digital computers. Microsonics can provide taps which are any sub-multiple of the total delay time up to 1600 microseconds and, with some limitations, output taps in delay lines from 1600 to 5000 microseconds.

Data sheets available on request.



Range Markers

Microsonics Range Markers are a specialized variation of ultrasonic solid lines produced specifically to meet the needs of the radar industry for precision test pulses which are inherently accurate and can be used for reference and calibration.

Data sheets available on request.

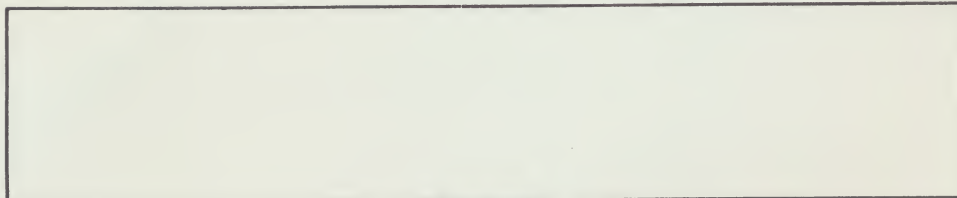


Crystal Filters

Microsonics manufactures Crystal Filters covering the frequency range from 100 kc to 100 mc. Band pass, band reject and discriminators are produced to the highest quality standards and military specifications. Bulletin 4350 covering design principles and theoretical limitations is available upon request.

Data sheets available on request.

Represented By



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